

Electrifying Clinics in Rural Ghana

Developing a system design

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INTRODUCTION

The clinic electrification project was established by Sindicatum Climate Change Foundation as a means of undertaking carbon dioxide emissions reduction projects that are not of sufficient scale to be funded by conventional streams of carbon finance. The aim of the project is to install clean electricity generating systems on clinics in remote rural parts of Ghana, initially in the environs of Kumasi. A range of technical options were postulated to achieve this: electricity could be provided by solar photovoltaics or diesel gensets, supported by the grid where available. System reliability could be provided either by running the microgeneration as back-up to the grid, or by running the system in conjunction with a battery storage array. All these options have the potential to reduce CO₂ emissions, as well as providing a significant increase in energy service, both in terms of the amount of energy delivered, its reliability and power quality.

A site visit was undertaken in April 2009 in order to monitor the electricity use in three of the proposed clinics. However, these site visits revealed little or no electricity use within the clinics. Room lighting was sparse, and there was no cooling, even in the form of ceiling fans, for patient comfort. There was no refrigeration, dramatically reducing the stock of medicines that could be stored, and shortening the lifetime of those that were present. The clinics, therefore, fell short in terms of the electrical equipment required to run a fully functioning clinic.

This posed a challenge for the design of an electricity system for the clinics. In the absence of real data from the sites, energy use and peak power demand can only be estimated by modelling. However, additional clinics were found in more urban locations, which functioned more ideally. These locations had lighting, cooling refrigeration, some air conditioning and also laboratories and associated electrical equipment (ultrasound, centrifuges *etc.*). The additional clinics were monitored to provide empirical data that can be used as a model of how the rural clinics might function if fully equipped. This report details the development of a system design for the rural clinics, incorporating both theoretical modelling of desired electricity loads, supported and validated by the evidence base of data from the monitored urban clinics.

Importantly, when designing the system it is necessary to include a social component to the calculations. The rural clinics are at present understaffed, and those staff present are often under-qualified to provide adequate care. There is a great need to attract doctors to these remote rural clinics, but it has proved difficult to attract doctors to these areas, especially with no amenities or electricity supply. One of the key factors in determining what electricity loads should be powered by the generation system is what loads will be required to attract a qualified doctor to the clinic. It is suggested that air conditioning in the doctors office would be an important factor in getting the clinics to attract staff and function properly. Therefore despite its exceedingly high electricity and power demands, installing air conditioning is considered as a viable possibility for the clinics.

The rest of this report provides an overview of the context of the Ghanaian electricity system, before presenting an analysis of the monitored data and the conclusions that can be drawn therefrom. The report then details the technical options available for each individual system component, before presenting the authors optimised system design. Cost estimates and ongoing monitoring requirements are presented, alongside a discussion of potential supply chain options for establishing a replicable stream of similar projects.

ELECTRICITY GENERATION IN GHANA

In 2006, 8429 GWh of electricity were generated, which after a small amount of export left 8303 GWh for domestic supply.¹ This is sufficient to provide 6519 GWh of electricity to end users, after high distribution losses of 1318 GWh (16%). The generation mix is two-fold: 67% comes from hydro power stations, mainly on Lake Volta, whilst the other 33% is generated by two oil fired power stations. This mix is, however, variable and strongly dependent on rainfall and the levels of stored water in Lake Volta. In 2007, the water level of Lake Volta, the largest man-made lake in West Africa was at an all-time low, 234.96 ft below the critical minimum. The lack of water in the lake created a 300 MW power shortfall and an average of just 12 hours electricity per day.²

It has been estimated that 45-47% of Ghanaians, including 15-17% of the rural population, have access to grid electricity, with a per capita electricity consumption of 358 kWh.³ However, electricity supply from the grid is not reliable, with brown-outs and black-outs common. It is common for larger end users, and wealthier residential properties to have a back-up diesel generator in order to ensure continuity of supply. The diesel generators run inefficiently, being sized to meet peak power demand, as opposed to average, and so are profligate users of primary fuel and a significant source of CO₂ emissions. Use of diesel gensets in this manner is the typical means of powering off-grid locations like the clinics visited.

In rural areas, grid access is less common, although some infrastructure is in place. However, whilst the transmission and distribution lines exist, connection of villages and buildings to this infrastructure is more complicated. St. Thomas' Clinic has transmission lines passing within 10m of the building, and has done since the 1970s. Despite this, the clinic has never been connected to the grid. Furthermore, even if it were connected, the reliability of the grid in such a remote location would be poor, both due to physical problems (trees falling across transmission lines) and electrical (voltage control and stability will be poor in remote locations).

With electricity demand set to grow by 8-10% *per annum* extra generation capacity will be required in order to meet this.⁴ It is estimated an extra 200MW will be required each year. At present an extra 3GW of capacity are planned to be installed by 2015, capable of generating an excess of electricity, even for Ghana's rapidly growing demand. The excess will be fed into the West African Power Pool, an international electricity grid currently in development, and expected to improve reliability of supply across the region by providing diversity and dependable infrastructure. The supply is likely to be oil fired thermal plant.

It is also recognised that distribution networks will have to be strengthened to provide a reliable electricity system and reach targets for rural electrification. The government has a target to provide 80-90% coverage by 2015.⁴ A village is considered electrified if it is accessed by the grid, and has a transformer installed for low voltage distribution. The Electricity Company of Ghana has wiring regulations which stipulate requirements for domestic wiring. Once in place, then they can be connected to the grid and get an electricity meter installed, for which ECG will charge US\$400. A further scheme exists to promote rural electrification for areas where no grid exists. If residents can provide the poles for the electricity pylons, then ECG will install the network extension.

Although there are ambitious plans for Ghana's electricity system, increasing the amount of electricity supplied, increasing access and improving system reliability, there are no guarantees that a reliable supply will be installed to the remote clinics under consideration in this project, and certainly no fixed timeline. In the meantime, the clinics remain in urgent need of upgrading of facilities and sufficient investment to attract doctors to the bush. These combined factors of lack of grid access and

unreliability of the grid, even if connected, imply that the systems designed for the clinics should be able to operate reliably without grid connection.

REVIEW OF MONITORED DATA

The Professors Clinic

In the absence of electricity loads at the proposed sites, it proved possible to monitor a clinic in an urban location to inform the project about the size of loads to be expected. The three phases of the supply into the Professor's clinic were monitored for 3 days at interval of 2 minutes, one phase of which is shown in Figure 1.

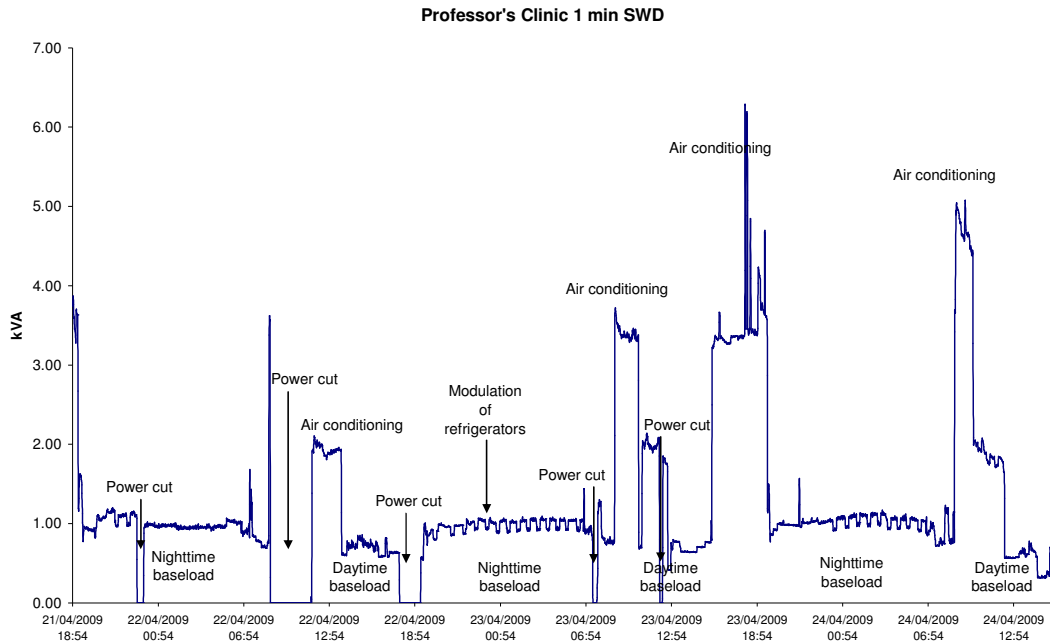


Figure 1 2 minutely data on 1 phase of the supply of the Professor's clinic

The collected data reveals some interesting conclusions which can be translated to the context of the rural clinics:

- Due to blackouts on the grid, there was no supply for approximately 8% of the time at the clinic. In a rural context, one would expect this figure to be even higher, illustrating the importance of designing a system capable of operating entirely off-grid.
- The largest power draw is the air conditioning loads, but in energy terms this is not so significant. This is because the run-time of the air conditioning is moderately small – the cooling service provided by the air conditioning units can be achieved with a run time of just 4 hours per day.
- The modulation observed is most likely from a refrigeration load, which is cyclical in nature.
- The baseload electricity use at the clinic is higher at night than during the day, indicating a lighting load (either interior or exterior). The baseloads are moderately high, showing the importance of sourcing the most efficient appliances possible in order to minimise overall consumption.
- The clinics have an average consumption of 30 kVAh per day, for a fully equipped and functional clinic. It is estimated that the clinic is 2-3 times the size of the rural clinics visited, so the expected energy consumption here is

expected to be 10-15 kVAh per day. The monitoring has therefore provided a useful guideline as to the expected size of the consumption at the rural clinics once fully operational.

GENERATION SYSTEM COMPONENTS

PV modules

The solar photovoltaic modules convert the energy of light directly into DC electricity. Photovoltaics are sold on the basis of their peak capacity (kWp), which is a measure of the power produced by the modules in peak sunshine. Modules vary in efficiency by technology – the more efficient the module the less space 1kWp takes up. Although there are some differences in energy production per kWp between technologies, this is marginal, and the key purchasing decision should be that of price per kWp. Thus a multicrystalline silicon module, which represents a good trade-off between efficiency and price is likely to represent the best value for money. Such panels retail in Ghana at GHc976 for an 80W panel (or £6.10 per Watt)⁵. In the UK, Sharp⁶ 170W panels can be supplied at a price of £425, just £2.50 per W⁷. Even with the cost of transport there are large savings to be made from importing panels from the UK.

The amount of PV modules needed will depend on the daily energy requirements of the electrical loads in the clinics. Under Ghana's climatic conditions, it is estimated that 1kWp would produce 1450 kWh *per annum* (See Figure 2).⁸

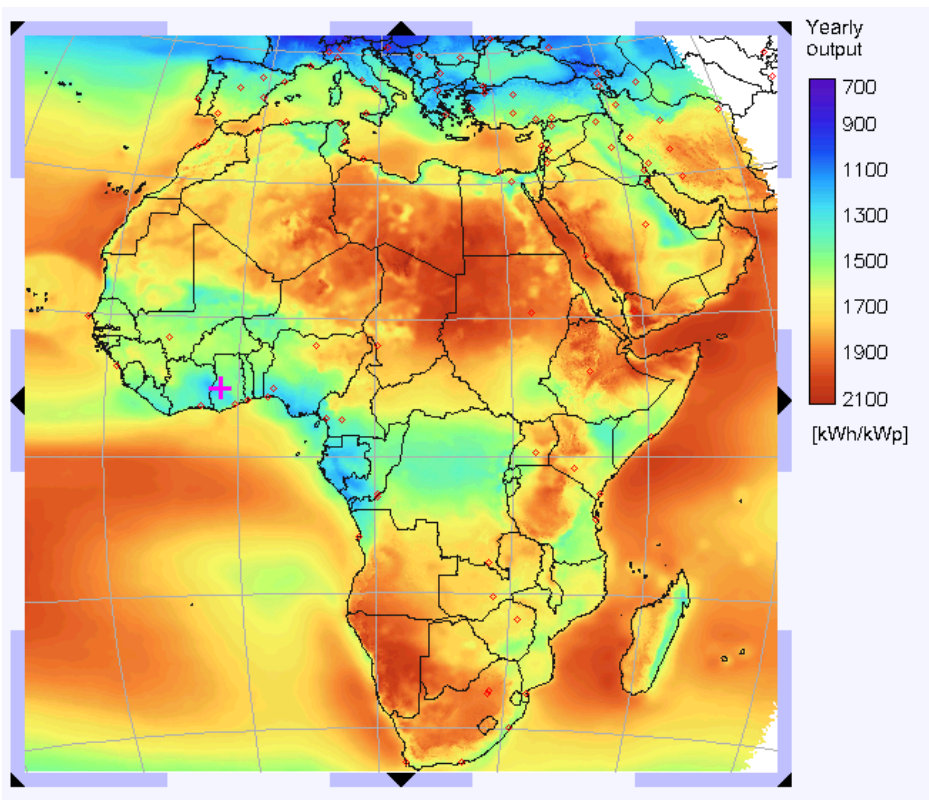


Figure 2 Annual PV electricity yields in Africa

Considering Ghana's location close to the equator, there is a substantial seasonal variation in output (Figure 3). Energy yields vary from 5.2 kWh/kWp per day in January and February to just 2.6 in September.

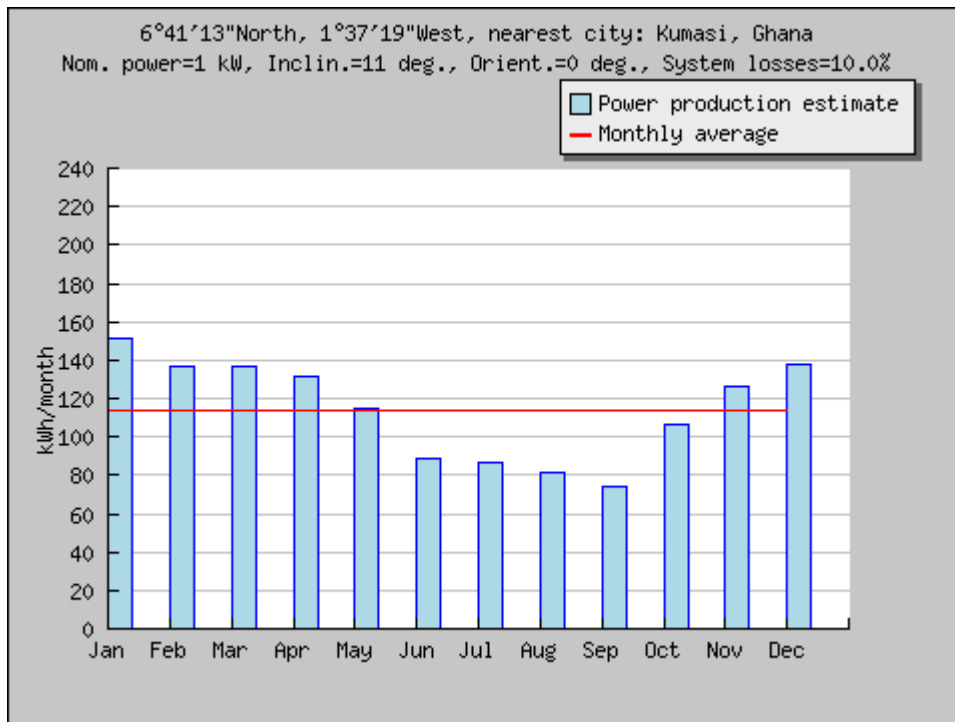


Figure 3 Seasonal output of a 1kW PV system in Kumasi, Ghana.

There are two approaches to overcoming this seasonal variation. First, one could install a system where average September output is sufficient to meet average daily demand, and use the battery system to ride through daily variations in system output. The second approach would be a system where average daily output over the year (4 kWh/kWp) is sufficient to meet average demand, and a much larger battery system or back-up generator is used to ride through seasonal variations in output. A cost analysis has revealed that the most economic solution is to size the PV to average yearly demand, and use a small petrol genset to provide back-up power in the rainy season.

PV modules are extremely durable and have a guaranteed lifetime of 25 years. However, being encapsulated in glass, they are moderately fragile to transport. Modules come in packs of 2 boxed in cardboard, and this should be sufficient protection even for the rough roads in Ghana, if securely tied down.

PV mounting systems

The PV modules are mounted on the roof on a support structure, that sits on top of the roof, but is fixed to structural beams inside the building. The structure also lifts the array off the roof slightly, allowing a cooling airflow behind the panels, which is important for keeping solar conversion efficiencies high. A wide range of commercial solar support structures are available (e.g. Unirac⁹) but these support structures are designed for use on western tiled roofs and standardised roof joists, and are expensive – typically 10–15% of the total cost of an installation in the UK.

Roofs in Ghana are characterised by corrugated roofs mounted over a loose wooden frame of indeterminate dimensions. Therefore a mounting system needs to be developed for use on the corrugated roofs that can be attached to the underlying wooden roof joists (See Figure 4).



Figure 4 Wooden roof structure at MIA clinic

It is recommended that Unistrut beams¹⁰ are attached to the roof, and screwed into the roof joists. The Unistrut beams are a conventional building product, and so are cheaper than the more bespoke solar mounting structures. The beams are U-shaped, and spring loaded washers can be inserted into the groove. A bolt and washer through this washer will attach the solar panel to the support structure. Some additional metal pieces will be needed to provide an edge for the washers on the edge of the arrays, and this can be sourced locally.

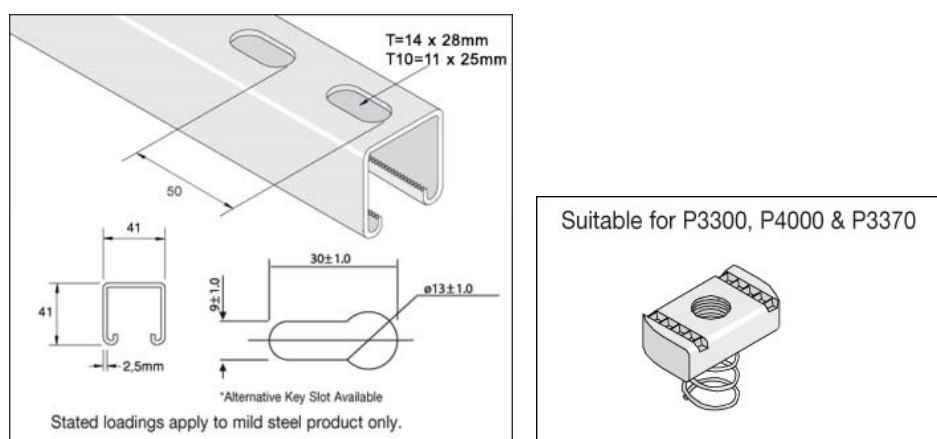


Figure 5 Unistrut racking – the beams are screwed through the holes to the roof joists. The spring mounted washer to which the panels bolt sits in the groove.

Solar Charge controller

The solar charge controller acts as the interface between the solar PV array and the batteries. It prevents the solar array from overcharging, and consequently damaging the batteries

There is only really one type of solar charge controller suitable for applications of this size, and that is the Outback FLEXmax.¹¹ These are 'Maximum Power Point' tracking – meaning that they extract as much energy from the panels as possible, they have minimal conversion losses, they are highly durable, and they are able to accommodate a wide range of panel configurations. There are two models:

- FLEXmax 60: for use with solar arrays up to 1800W with a 24V battery
- FLEXmax 80: for use with solar arrays up to 2500W with a 24V battery



Figure 6 FlexMax Solar Charge Controller

Prices: 60 - £587.49; 80 - £638.55 each

Batteries

The 24V DC battery for each system is to be made up of 12 cells selected from the Exide Sonnenschein A600 Solar 2V OPzV range.¹² The range offers long-life (10 years +), durability, excellent tolerance to high ambient temperatures, and minimum maintenance. The cells are tough, highly unlikely to be damaged in transit and classed as safe for air-freight.

Further details about the range taken from the product brochure are shown below illustrating the number of possible cycles as a function of the average depth of discharge. The second graph illustrates the dependence of the battery life on the ambient temperature, showing the importance of keeping the batteries safely stored in a cool location.

The batteries will be specified that their average daily depth of discharge is 33% of their C10 (ten hour discharge rate) capacity (*i.e.* that at the end of each night they still hold two-thirds of their charge). This charging regime should permit at least 3,500 cycles. The actual depth of discharge can vary between 0 and 100% without causing the cells any harm, though such conditions would be sub-optimal and would affect battery life. Ideally, the daily depth of discharge will be between 15 and 60% and will average out at 33%, as previously mentioned.

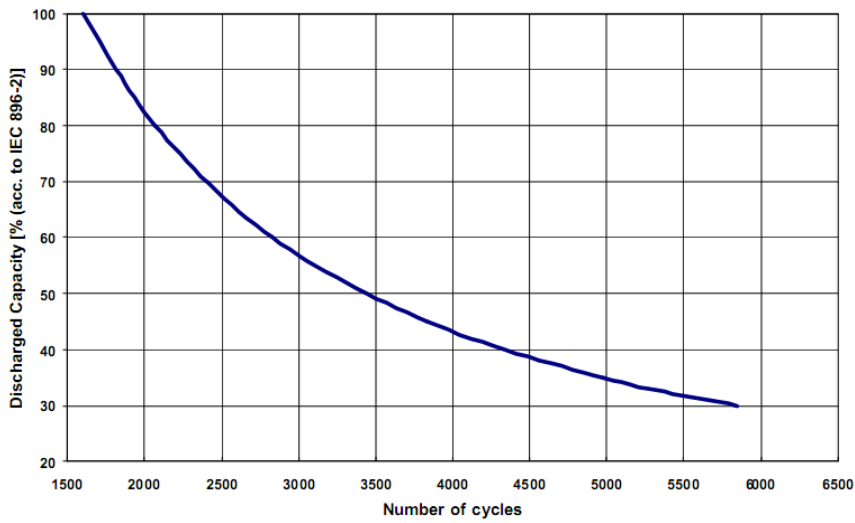


Fig. 16: A 600 SOLAR, Number of Cycles vs. Depth of Discharge (DOD)

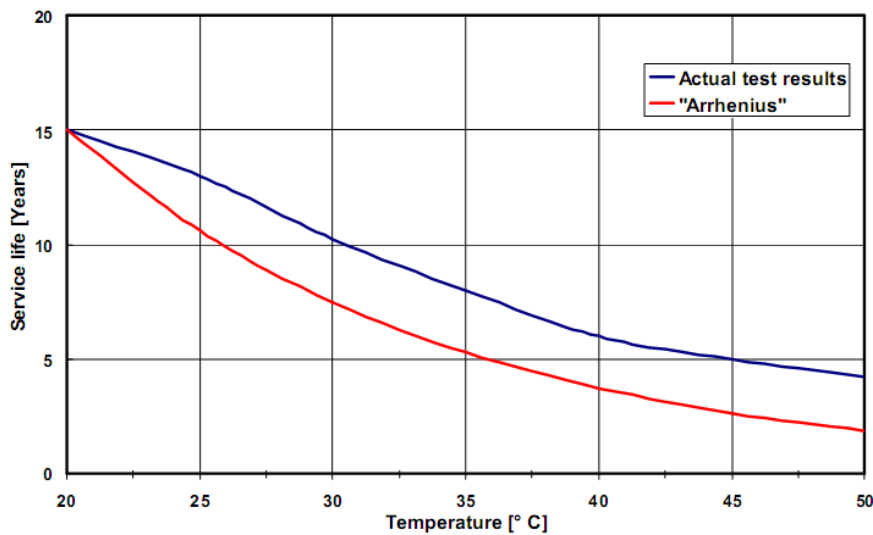


Fig. 22: A 600, Service Life vs. Temperature. A 600 follows the blue curve. The equivalent for A 600 SOLAR regarding number of cycles (15 years at 20° C = 100% number of cycles).

Figure 7 Performance of Exide Sonnenschein A600 Solar 2V OPzV batteries

Technical characteristics and data

Type	Part number	Nominal voltage V	Nominal capacity C ₁₀₀ 1.85 V/C Ah	Dis-charge current I ₁₀₀ A	Length (l) max. mm	Width (b/w) max. mm	Height up to top of cover (h1) max. mm	Height incl. connectors (h2) max. mm	Installed length (B/L) mm	Weight approx. kg	Terminal	Pole pairs
5 OPzV 300	NGS6020300HS0FA	2	300	3.0	126	208	360	398	134	23.5	F-M8	1
6 OPzV 360	NGS6020360HS0FA	2	360	3.6	147	208	360	398	155	28.0	F-M8	1
5 OPzV 400	NGS6020400HS0FA	2	400	4.0	126	208	475	513	134	31.0	F-M8	1
6 OPzV 500	NGS6020500HS0FA	2	500	5.0	147	208	475	513	155	36.5	F-M8	1
7 OPzV 600	NGS6020600HS0FA	2	600	6.0	168	208	475	513	176	42.0	F-M8	1
6 OPzV 720	NGS6020720HS0FA	2	720	7.2	147	208	650	688	155	50.0	F-M8	1
8 OPzV 960	NGS6020960HS0FA	2	960	9.6	215	193	650	688	220	68.0	F-M8	2
10 OPzV 1200	NGS6021200HS0FA	2	1200	12.0	215	235	650	688	220	82.0	F-M8	2
12 OPzV 1400	NGS6021400HS0FA	2	1400	14.0	215	277	650	688	220	97.0	F-M8	2
12 OPzV 1700	NGS6021700HS0FA	2	1700	17.0	215	277	800	838	220	120.0	F-M8	2
16 OPzV 2300	NGS6022300HS0FA	2	2300	23.0	215	400	775	815	223	160.0	F-M8	3
20 OPzV 2900	NGS6022900HS0FA	2	2900	29.0	215	490	775	815	223	200.0	F-M8	4
24 OPzV 3500	NGS6023500HS0FA	2	3500	35.0	215	580	775	815	223	240.0	F-M8	4

Capacities C₁ – C₁₀₀ (20°C)

Type	Capacities C ₁ – C ₁₀₀ (20°C)				
	C ₁ 1.67 V/C	C ₃ 1.75 V/C	C ₅ 1.77 V/C	C ₁₀ 1.80 V/C	C ₁₀₀ 1.85 V/C
4 OPzV 240	108	151	175	200	240
5 OPzV 300	135	189	219	250	300
6 OPzV 360	162	227	263	300	360
5 OPzV 400	180	252	292	350	400
6 OPzV 500	225	315	365	420	500
7 OPzV 600	270	378	438	490	600
6 OPzV 720	324	454	526	600	720
8 OPzV 960	432	605	701	800	960
10 OPzV 1200	540	756	876	1000	1200
12 OPzV 1400	630	882	1022	1200	1400
12 OPzV 1700	765	1071	1241	1500	1700
16 OPzV 2300	1035	1449	1679	2000	2300
20 OPzV 2900	1305	1827	2117	2500	2900
24 OPzV 3500	1575	2205	2555	3000	3500

Drawings with terminal position, terminal and torque

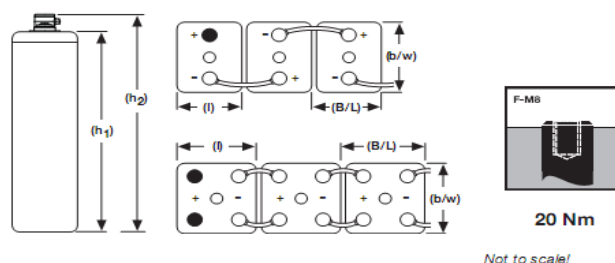


Figure 8 Technical characteristics of Exide Sonnenschein A600 Solar 2V OPzV batteries

The Exide Sonnenschein A600 Solar 2V OPzV series is chosen as is the **only** gelled battery available on the market offering the characteristics required and indicative prices are shown below. The exact model and size of array used will depend on the daily electricity demand for each clinic:

- 240/2v A600: £139.46 / €152.01 (Ex VAT at 15%)
- 300/2v A600: £161.31 / €175.83 (Ex VAT at 15%)
- 360/2v A600: £188.39 / €205.35 (Ex VAT at 15%)
- 400/2v A600: £190.37 / €207.50 (Ex VAT at 15%)
- 500/2v A600: £224.44 / €244.64 (Ex VAT at 15%)
- 600/2v A600: £250.87 / €273.45 (Ex VAT at 15%)
- 720/2v A600: £274.05 / €298.71 (Ex VAT at 15%)
- 960/2v A600: £376.54 / €410.43 (Ex VAT at 15%)
- 1200/2v A600: £451.07 / €491.67 (Ex VAT at 15%)
- 1400/2v A600: £522.10 / €569.09 (Ex VAT at 15%)
- 1700/2v A600: £604.59 / €659.00 (Ex VAT at 15%)
- 2300/2v A600: £817.44 / €891.01 (Ex VAT at 15%)
- 2900/2v A600: £1,041.03 / €1,134.72 (Ex VAT at 15%)
- 3500/2v A600: £1,196.65 / €1,304.35 (Ex VAT at 15%)

The alternative would be to go for wet OPzS cells. For a similar performance, these would be around two-thirds cheaper to buy but would be vulnerable to poor maintenance and damage in transit. Such a battery would also require significant additional expertise from the staff of the clinics.

Battery Monitor

To enable the clinic to keep an eye on its energy use, a battery monitor¹³ should be installed. The battery system voltage will decrease as the batteries discharge, so a measurement and display of the battery voltage will give an indication of the batteries state of charge and therefore whether the stand-by generator should be used, or the air-con switched off, etc.



Figure 9 Victron Battery monitor

Unit Price: £153.85

Inverter

While most of the loads at the clinics are to be powered directly from the battery, a good quality source of 230V mains quality electricity will also be required for plug loads. There is a great variety of inverters available, ranging from cheap “square-wave” units to ultra-precision “sine-wave” units. Both types convert the 24V direct current from the battery into 230V alternating current at mains frequency (50Hz). The latter type gives a better approximation of the sine-wave expected by some of the more sensitive mains appliances, and – since medical equipment may be in use – is therefore recommended. The inverters are designed to operate off-grid only – on-grid operation would require an inverter to match the phase of its output to that of the grid, but crucially this means grid-tied inverters do not operate if the grid is down. The system has been designed for off-grid supply only, such that the clinics have a reliable continual supply and that grid-connection is not necessary.

A great range of sine-wave inverters exist. Under normal operating conditions, all will provide a superior quality of power supply to that currently available on the mains electricity in Ghana. They range in price according to size and quality of design. The better designed ones will have a lower standby current draw and can usually pay for their additional cost through reduced energy losses.



Figure 10 Studer SI-824 inverter

The inverter provisionally selected for use is a Studer SI-824.¹⁴ It has a nominal rating of 800W but can handle significant overloads for short periods. It has a standby consumption of 2.8W (about 10W lower than average, and equivalent to 240Wh per day).

Input voltage	Min. - Max.: $U_{nom} \times 0.95$ to $U_{nom} \times 1.33$
Dynamic correction of U_{min} .	- 10% at P_{nom}
Output voltage	True sine 230 Vac $\pm 3\%$
Distortion	<math>< 2\%</math> (at P_{nom})
Dynamic behaviour	From 0% to 100% load change. Normalization: 0.5 ms
Frequency	50 Hz $\pm 0.01\%$ (Crystal control)
Charge detection (standby)	Adjustable: 0.3 \rightarrow 20 W
Maximum power 15 min	1.3 – 1.6 x P_{nom} / 25°C
Maximum power 3 min	1.6 – 2 x P_{nom} / 25°C
Peak power 5s	3.5 x P_{nom}
Asymmetric load	Up to 2 x P_{nom}
Cos ϕ	0.1 – 1
Protections	Overload/Overheat/Short-circuit/Reverse polarity by internal fuse
IP protection index	IP 20 complies with DIN 40050/IP 23 with top cover
Forced ventilation	From 45°C \pm 3°C
Overheating protection	75°C \pm 3°C
Required battery capacity	> 5x P_{nom}/U_{nom} (recommended value)
Acoustic level	Without ventilation: <math>< 10</math> dB With ventilation: <math>< 35</math> dB
EEC conformity	EN50081 I/II, EN 55014 - EN 55022, EN 61000-3-2 IEC 801 I/II/III/IV, CEI 555, IEC 1000-3-2, LVD 73/23/EEC

Figure 11 Technical characteristics of Studer SI-824 inverter

Back-up generator

The wide range of solar insolation received at different times of year (see Figure 3) means that there may be times in the rainy season when insufficient insolation is received. Rather than provide more solar panels, which would then have to spill energy in the sunny season, it proves more economic to incorporate a small back-up generator to provide year round security of supply. This diversity of supply adds system resilience, although it is estimated the diesel may only operate for 100 hours per year.

There are many possibilities for back-up generators, nearly all of which involve generating 230V AC and putting this back into the battery through a charger. There are conversion losses involved with this process.

A company in Australia is manufacturing 1200W 24V DC generators.¹⁵ The design principle is extremely simple:

- A Honda GX160 engine is coupled directly to a 24V alternator
- The alternator output is regulated by a charge controller such that the correct amount of current is supplied to the battery

The units are petrol driven. The petrol consumption will vary with the amount of amps being drawn from the compressor as the engine varies its speed. This makes for a very efficient way of generating electrical energy from fossil fuels, and should provide at least 2.5 kWh per litre. Because the generator is connected to the batteries it can run at maximum efficiency, whereas a load-following generator (as is conventional in Ghana) would be running inefficiently at partial load.



Figure 12 Honda 1200W petrol genset

Weight: 25kg.

Price: £950 (A\$1,895)

ELECTRICAL LOAD COMPONENTS

As well as installing a generating system, efficient end use products have been sourced for the project. These have been chosen to meet the highest standards of energy efficiency, in order to provide the maximum level of energy service per unit of electricity generated and to allow the electricity generating system to be sized as small, and therefore cheaply, as possible.

Ceiling Fans

Ceiling fans are usually designed to run on AC mains electricity. They are not particularly efficient – a 42" version using around 30W at mid speed settings. In a battery-based stand-alone system, one must add DC to AC conversion losses to this figure.

However, DC ceiling fans are available.¹⁶ The advantages are:

- Run directly from the batteries – no conversion losses
- DC motors are at least twice as energy efficient as equivalent AC motors
- DC motors tend to outlive AC motors
- Extra Low Voltage – no electric shock hazard

Datasheet – 12V Ceiling Fan



Model DC12-103 WE
103cm (42") diameter, color: white, 4 white MDF-wings
incl. 4-step speed controller

Step	RPM	Current Consumption
1	154	1,29A
2	124	0,75A
3	93	0,38A
4	54	0,17A

Figure 13 12V DC ceiling fan

The main disadvantages are that replacements are unlikely to be available locally in Ghana and they cost around 50% more than equivalent AC units – however these costs are outweighed by the reduced associated capital costs of supply infrastructure resulting from their higher efficiency.

The manufacturers of the fan shown have confirmed that it will run happily on 24V DC – better, in fact, than the 12V at which it is rated.

Approx unit cost: £150. Suggest one spare per clinic.

Lighting

Compact fluorescent lights (CFLs) will be used throughout. The units will be 15W (equivalent to 60W normal incandescent bulb) and will run on 24V DC using standard E27 fittings.¹⁷

The reasons for choosing 24V DC lighting (over more readily available and cheaper 230V mains lighting) are as follows:

- They can be powered from the same cabling infrastructure used by the fans
- Run directly from the batteries – no conversion losses
- Extra Low Voltage – no electric shock hazard
- Their inbuilt inverters mean lower levels of harmonic distortion than would be the case for mains versions



Figure 14 12V DC compact fluorescent lightbulb

Approx unit cost: £7.60. Suggest one spare per one fitted.

Refrigeration

Refrigeration units are required for the store of vaccines, to allow higher levels of care to be delivered in the clinics. Refrigeration will be provided by highly energy efficient 24V DC Sundanzer 163Litre units¹⁸: one configured as a refrigerator, one as a freezer. The units are designed specifically for use in tropical conditions on solar power systems and are well-proven in the field.



Figure 15 24V DC Sundanzer refrigeration units

Product specifications are as follows:

- Gross Capacity: 5.8 cu. ft./163 liters
- Product Dimensions (W x D x H): 36.8 x 26.2 x 34.5 inches / 93.5 x 66.5 x 87.6 cm
- Shipping Dimensions (W x D x H): 39 x 30 x 39 inches / 99 x 76 x 99 cm
- Shipping Weight: 125 lb. / 57 kg.
- Daily Energy Use Refrigerator: 182 Wh
- Daily Energy Use Freezer: 531 Wh

Anticipated daily energy use is based on an assumed ambient average daily temperature of 82 deg F (28 Celsius):

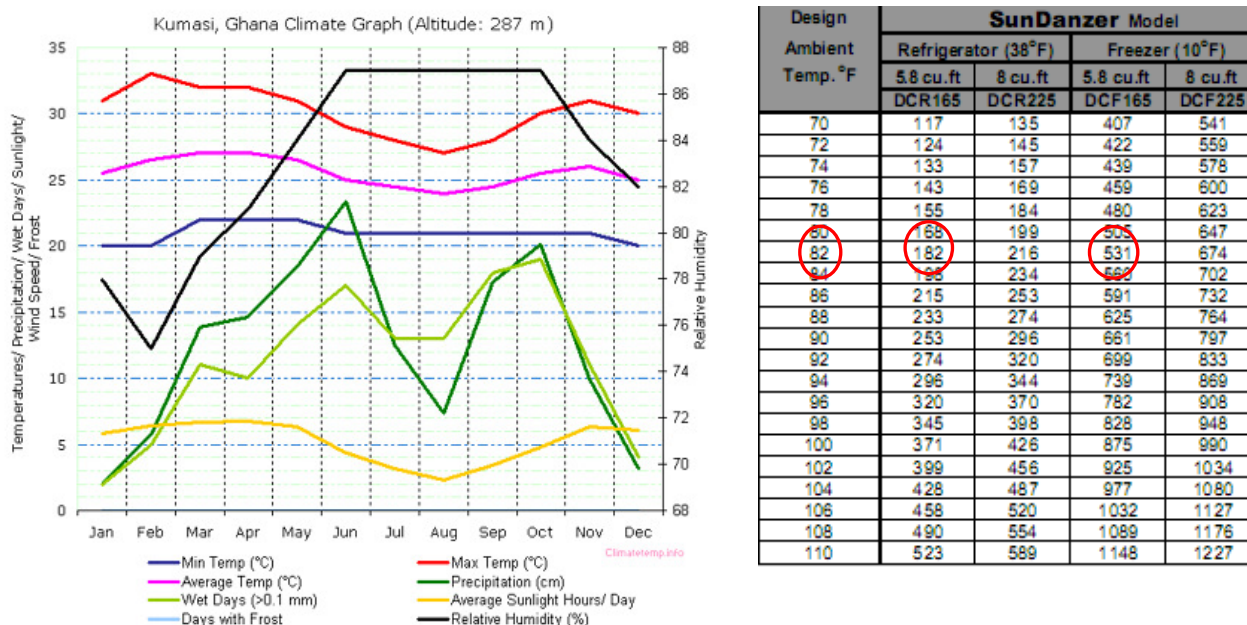


Figure 16 Technical characteristics of 24V DC Sundanzer refrigeration units

Unit Cost: £720 (refrigerator); £720 (freezer)

Air-Conditioning

The project has considered the provision of air conditioning in the doctor’s office as essential to attracting qualified staff to work in the bush. Air-conditioning sizing is complicated by a variety of factors other than ambient temperature, relative humidity and room size: subjective occupant comfort levels, insulation of room, house-keeping with regard to shutting doors and windows to outside, etc.

It was suggested 2.5 HP units should be used²⁰. A 2.5 HP unit is assumed to provide 6 kW of cooling output (conversion of input power to output cooling levels is an imperfect science owing to varying efficiencies of different units: the ratio used here is based on an assumed energy efficiency ratio of 3.2).

Since air-conditioning has the potential to use a significant portion of the energy generated on site (50% +) it is imperative that the most efficient unit be used:

The monitoring of the Professor’s clinic suggests that 4 hours of run time per day is sufficient to provide a significant cooling service to the rooms. At 4 hrs full load per day:

- A typical mains unit might use 7000 Wh per day
- The most efficient mains unit 4400 Wh per day

Given that the capital costs of the energy supply infrastructure are at least £1.50 per Wh per day, it can be seen that the investment in batteries and solar to run the units would be approximately £10,500 and £6,600 respectively.



Figure 17 24V DC air conditioning unit

An alternative 24V DC unit has been sourced.¹⁹ It is only available in the US but has an efficiency such that for the equivalent cooling output it uses 2200Wh per day, requiring a capital outlay in solar and batteries of 'only' £3,300. The unit cost is £1,900 compared with around £900 for the most efficient mains version giving a nett saving of £2,300. Furthermore, since the unit is powered directly by the batteries it removes the requirement for extra investment in inverter power – saving an additional £1,000.

SplitCool DC17 v.1		Indoor Unit:	
Nominal Cooling	5KW (17,000 BTU)	Height:	26 in
Nominal Power	552 Watts	Width:	22 in
Voltage	24 VDC (22-28v)	Depth:	8 in
Amps (max)	23	Air Flow:	540 cfm
COP	9.03	Noise Level (db):	43
EER	30.79	Outdoor Unit:	
Weight	155 lbs	Height:	12 3/4 in
Compressor	Rotary Vane Low	Width:	42 1/8 in
Low Voltage Disconnect	Yes	Depth:	8 7/8 in

Figure 18 Technical details of Split Cool 24V DC air conditioning unit

Unit cost: £1,900 (\$3,000)

Clinic Infrastructure

As well as the system components outlined above, key infrastructure work will have to take place at the clinics, before the installation of the generating system. These will include:

- DC wiring for lights, with accompanying switches and fittings
- DC wiring for the ceiling fans
- DC wiring for the refrigeration and air conditioning units

- AC wiring for any sockets required
- Cool housing space for battery array
- Housing for the back-up diesel genset

The DC wiring will have to be specified so as to minimise resistive losses which can be considerable at 24V. AC wiring and sockets can be sourced in Ghana and installed using local labour.

SYSTEM DESIGN AND COSTINGS FOR THE CLINICS

The following section presents the final proposed system designs for the two clinics at Ntoboroso and Hia. Each section presents a table of the electrical loads and their energy consumption in Wh and Ah per day.

The second table calculates the required battery storage capacity, based on a discharge to an average of 66% of capacity per day. A daily load of 100 Ah, would require a battery system of 300Ah to meet this requirement. This table then chooses the most appropriate battery system from a range of options, shown in bold.

The third table sizes the PV system to meet average demand over the course of the year. This minimises the amount of expensive PV required. In the rainy season this will lead to a small shortfall in daily energy, which can be met by the backup generator. This table also gives an indication of the number of hours the diesel will be required to run, with associated fuel requirements.

A fourth table shows costings for the loads and generating system. It should be noted that these are the cheapest prices that it has been possible to source via an internet search, with the exception of the PV, for which a firm quote has been provided. Costs are exclusive of VAT and shipping, the latter being highly dependent on the logistics of shipping to Ghana (see below). Therefore these costs should not be considered a quote, but indicative of the price that the systems would be expected to cost.

The fifth table provides a breakdown of the capital cost by load – that is to say the cost of the energy generating infrastructure is allocated in proportion to each of the loads. It provides an indication as to how much of the project cost is going to provide the service for that particular energy end use, and highlights the importance of sourcing the most energy efficient appliances possible. An end use that was half as efficient would have double the associated capital cost of supply.

Ntoboroso -Estimated Loads

DC Loads	Number	Power (W)	Hrs per Day	Wh per day	Ah per day
Indoor Lights (CFL)	29	15	6	2610	109
Outdoor Lights (CFL)	15	15	6	1350	56
Ceiling Fans	15	18	12	3240	135
165L Refrigerator	1	n/a	n/a	182	8
165L Deep Freeze	1	n/a	n/a	521	22
17,000 BTU Air Con	1	n/a	n/a	2200	92
Cables losses				505	21
				10608	442
AC Loads					
Desktop PC	1	60	8	480	20
Misc Socket loads	1	n/a	n/a	2000	83
Inverter Losses	1	n/a	n/a	241	10
				2721	113
Totals				13329	555

Ntoboroso - Energy Storage

Daily demand at 24Vnom DC	555 Ah
Daily demand as percent of C10	33%
Required C10 Battery Capacity	1683 Ah

Exide Sonnenschein A600 Dryfit

16/2300



C1	1035	Ah
C5	1449	Ah
C10	1679	Ah
C20	2000	Ah
C100	2300	Ah

Anticipated Battery Life: min 10 years

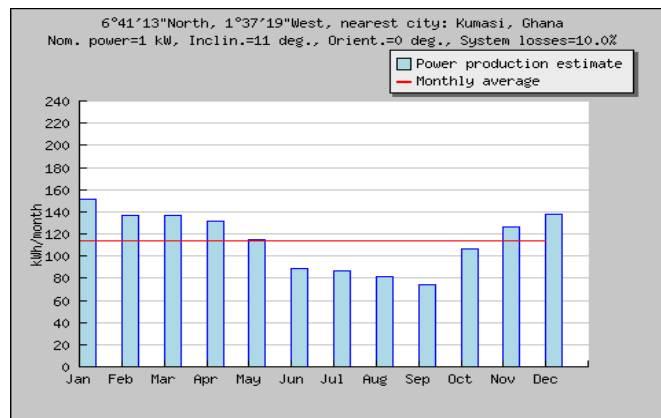
Price/unit	No Units	Total Price (£)
817.44	12	9809.28

kg/unit	No Units	Total Weight (kg)
160	12	1920

Unit Height (mm)	815
Unit Width (mm)	215
Unit Depth (mm)	400

Ntoroboso -Energy Supply

Daily Demand from Batteries	555 Ah
Charge Derating (Battery)	1.176
Charge Derating (Charge Contoller)	1.026
Daily Charging Requirements	670 Ah
Daily Charging Requirements	8.042 kWh
Annual kWh per kW PV in Kumasi	1,450 kWh
Annual kWh required at clinic	2,935 kWh
Monthly kWh required at clinic	245 kWh
Annualised kW installed PV required	2.02 kW



Suitable PV system size	2.5 kW
15 * 170W Sharp panels	2.55 kW
Annual kWh provided	3,698 kWh
Average monthly kWh provided	308 kWh

Monthly kWh required at clinic	245 kWh	Shortfall	hours back-up generator	litres petrol
Cloudy month: June	229.5 kWh	15 equals	13	6.3
Cloudy month: July	224.4 kWh	20 equals	17	8.4
Cloudy month: Aug	206.55 kWh	38 equals	32	15.9
Cloudy month: Sept	191.25 kWh	53 equals	44	22.2
Annual Totals			106	53

Ntoboroso - Prices

	Installed Number	Spares	Unit Price £	Total Price £
24V DC Loads				
Indoor Lights (CFL)	29	30	7.60	448.40
Outdoor Lights (CFL)	15	15	7.60	228.00
Ceiling Fans	15	1	150.00	2400.00
165L Refrigerator	1	0	720.00	720.00
165L Deep Freeze	1	0	720.00	720.00
17,000 BTU Air Con	1	0	1900.00	1900.00
Cables and fittings	n/a	n/a	n/a	300.00
				6716.40
230V AC Provision				
800W Inverter	1	0	923.00	923.00
Cables and fittings				300.00
				1223.00
Batteries				
A600 OPzV 16/2300	12	0	817.44	9809.28
Battery Monitor BMV 602				153.85
Cables and fittings	n/a	n/a	n/a	150.00
				10113.13
Solar System				
Sharp 170W panels	15	0	425.00	6375.00
Roof Mounting Kit	1	0	700.00	700.00
Charge Controller	1	0	638.55	638.55
Cables and fittings	n/a	n/a	n/a	200.00
				7913.55
Back-up Generator				
1200watt Petrol Honda DC	1	0	950.00	950.00
Cables and fittings	n/a	n/a	n/a	50.00
				1000.00
			Grand Total	26,966.08
			(ex delivery charges)	

Ntoboroso - Capital Expenditure per load

DC Loads	Number	Power (W)	Hrs per Day	Wh per Day	Assoc Cap Cost of Supply (£)	<i>Total Appliance Costs (£)</i>
Indoor Lights (CFL)	29	15	6	2610	3,928.86	<i>448.40</i>
Outdoor Lights (CFL)	15	15	6	1350	2,032.17	<i>228.00</i>
Ceiling Fans	15	18	12	3240	4,877.21	<i>2400.00</i>
165L Refrigerator	1	n/a	n/a	182	273.97	<i>720.00</i>
165L Deep Freeze	1	n/a	n/a	521	784.27	<i>720.00</i>
17,000 BTU Air Con	1	n/a	n/a	2200	3,311.69	<i>1900.00</i>
Cables losses				505	760.41	
			Total	10608	15,968.57	
AC Loads						
Desktop PC	1	60	8	480	722.55	
Misc Socket loads	1	n/a	n/a	2000	3,010.62	
Inverter Losses	1	n/a	n/a	364	547.93	
			Total	2844	4,281.11	
			Totals	13452	20,249.68	

Associated capital costs of supply: 1.5053 £/Wh/day

Associated capital costs of supply is the sum cost of the energy supply infrastructure £(1223+10113.13+7913.55+1000) = £20,249.68 divided by the daily energy requirements of each load. It is a good indicator of the IMPORTANCE of sourcing efficient appliances. It can be used for comparing the capital cost of the appliances with the capital expenditure required to run them.

1223.00
10113.13
7913.55
1000.00
20249.68

Hia - Estimated Loads

DC Loads	Number	Power (W)	Hrs per Day	Wh per day	Ah per day
Indoor Lights (CFL)	10	15	6	900	38
Outdoor Lights (CFL)	4	15	6	360	15
Ceiling Fans	4	18	12	864	36
165L Refrigerator	1	n/a	n/a	182	8
165L Deep Freeze	1	n/a	n/a	521	22
17,000 BTU Air Con	1	n/a	n/a	2200	92
Cables losses				251	10
				5278	220
AC Loads					
Desktop PC	1	60	8	480	20
Misc Socket loads	1	n/a	n/a	1500	63
Inverter Losses	1	n/a	n/a	206	9
				2186	91
			Totals	7464	311

Hia - Energy Storage

Daily demand at 24Vnom DC	311 Ah
Daily demand as percent of C10	33%
Required C10 Battery Capacity	942 Ah

Exide Sonnenschein A600 Dryfit **12/1400**



C1	630 Ah
C5	882 Ah
C10	1022 Ah
C20	1200 Ah
C100	1400 Ah

Anticipated Battery Life: min 10 years

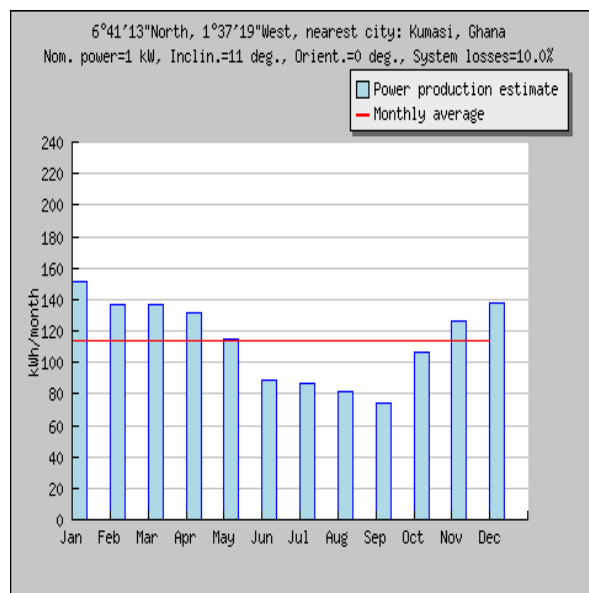
Price/unit	No Units	Total Price (£)
522.1	12	6265.2

kg/unit	No Units	Total Weight (kg)
97	12	1164

Unit Height (mm)	688
Unit Width (mm)	215
Unit Depth (mm)	277

Hia - Energy Supply

Daily Demand from Batteries	311 Ah
Charge Derating (Battery)	1.176
Charge Derating (Charge Contoller)	1.026
Daily Requirements Charging	375 Ah
Daily Requirements Charging	4.503 kWh
Annual kWh per kW PV in Kumasi	1,450 kWh
Annual kWh required at clinic	1,644 kWh
Monthly kWh required at clinic	137 kWh
Annualised kW installed PV required	1.13 kW



Suitable PV system size	1.5 kW
9 * 170W Sharp panels	1530 kW
Annual kWh provided	2,219 kWh
Average monthly kWh provided	185 kWh

Monthly kWh required at clinic	Shortfall	hours back-up generator	litres petrol
Cloudy month: June	135 kWh	2 equals	0.8
Cloudy month: July	132 kWh	5 equals	2.1
Cloudy month: Aug	121.5 kWh	15 equals	6.4
Cloudy month: Sept	112.5 kWh	24 equals	10.2
Annual Totals		39	20

Hia - Prices

	Installed Number	Spares	Unit Price £	Total Price £
24V DC Loads				
Indoor Lights (CFL)	10	10	7.60	152.00
Outdoor Lights (CFL)	4	4	7.60	60.80
Ceiling Fans	4	1	150.00	750.00
165L Refrigerator	1	0	720.00	720.00
165L Deep Freeze	1	0	720.00	720.00
17,000 BTU Air Con	1	0	1900.00	1900.00
Cables and fittings	n/a	n/a	n/a	250.00
				4552.80
230V AC Provision				
800W Inverter	1	0	923.00	923.00
Cables and fittings	n/a	n/a	n/a	150.00
				1073.00
Batteries				
A600 OPzV 12/1400	12	0	522.1	6265.20
Battery Monitor BMV 602	1	0	153.85	153.85
Cables and fittings	n/a	n/a	n/a	150.00
				6569.05
Solar System				
Sharp 170W panels	9	0	425.00	3825.00
Roof Mounting Kit	1	0	500.00	500.00
Charge Controller	1	0	587.49	587.49
Cables and fittings	n/a	n/a	n/a	150.00
				5062.49
Back-up Generator				
1200watt Petrol Honda DC	1	0	950.00	950.00
Cables and fittings	n/a	n/a	n/a	50.00
				1000.00
			Grand Total	18,257.34
			(ex delivery charges)	

Hia - Capital Expenditure per load

DC Loads	Number	Power (W)	Hrs per Day	Wh per Day	Assoc Cap Cost of Supply (£)	<i>Total Appliance Costs (£)</i>
Indoor Lights (CFL)	10	15	6	900	1,623.47	<i>152.00</i>
Outdoor Lights (CFL)	4	15	6	360	649.39	<i>60.80</i>
Ceiling Fans	4	18	12	864	1,558.53	<i>750.00</i>
165L Refrigerator	1	n/a	n/a	182	328.30	<i>720.00</i>
165L Deep Freeze	1	n/a	n/a	521	939.81	<i>720.00</i>
17,000 BTU Air Con	1	n/a	n/a	2200	3,968.49	<i>1900.00</i>
Cables losses				251	453.40	
			Total	5278	9,521.39	
AC Loads						
Desktop PC	1	60	8	480	865.85	
Misc Socket loads	1	n/a	n/a	1500	2,705.79	
Inverter Losses	1	n/a	n/a	339	611.51	
			Total	2319	4,183.15	
			Totals	7597	13,704.54	

Associated capital costs of supply: 1.8039 £/Wh/day

Associated capital costs of supply is the sum cost of the energy supply infrastructure $\pounds(1073+6569.05+5062.49+1000) = \pounds 13,704.54$ divided by the daily energy requirements of all loads and then multiplied by each individual load. It is a good indicator of the IMPORTANCE of sourcing efficient appliances. It can be used for comparing the capital cost of the appliances with the capital expenditure required to run them.

1073.00
6569.05
5062.49
1000.00
13704.54

CO₂ Implications

It is important to note that the clinics are receiving a large increase in the level of service provided in terms of lighting cooling and electrical loads. There is a small carbon consequence from this due to the way the system has been designed. The clinics at Ntoboroso and Hia will be combusting a small amount of petrol in the generator to back-up during the rainy season – 53 litres and 20 litres *per annum*, respectively. This corresponds to annual CO₂ emissions of just 122 kg and 46 kg, respectively.

If the clinics were run by a load following diesel genset, as would be conventional for an off-grid location in Ghana, the diesel would be operating inefficiently (*ca.* 18% load), resulting in a *daily* consumption of 37 and 23 litres of diesel. This corresponds to annual CO₂ emissions of 36 and 23 tonnes of CO₂ respectively. It should also be remembered that this is the carbon footprint required to run the efficient end-use appliances, and that less efficient end use could double these carbon footprints.

ONGOING OPERATION

Maintenance requirements

The system has been designed to minimise maintenance requirements over the course of its lifetime. The PV panels are virtually maintenance free, having no moving parts, but will need to be kept free of leaves and debris in order to maintain optimal operation. The panels are self cleaning at an angle of greater than 15°, so dust may accumulate on the panels at the clinics visited. An annual wash will ensure optimum performance. The batteries have been chosen so as to not require maintenance (topping up *etc.*). The diesel generator will need occasional maintenance, but the short annual run-times will minimise this requirement.

Estimated Lifetime of components

The solar PV panels come with a 25 year operational guarantee, which will be passed on to the system owner. The batteries will have a shorter lifetime, estimated at 3500 cycles, or 10 years. Similarly, the charge controller and inverter would be expected to have a lifetime of ten years.

As far as the electrical loads are concerned, DC appliances have a longer lifetime than their AC counterparts. Lifetime here will be dependent on the extent of use, but it would not be unreasonable to expect these devices to have a lifetime of 10 years.

SHIPPING AND LOGISTICS

In terms of project management, there are various options for the procurement of the equipment needed. The trial installations will allow these options to be assessed, and ultimately this process needs to become streamlined so that it can be replicated at further clinics over the coming years. The supply chain also needs to be established and sustained in the long-term so that replacement components are available in case of failure.

Three different approaches are suggested:

Use Components sourced in Ghana

In terms of ensuring ongoing access to components, it would seem sensible to procure all equipment in Ghana. However, with much of the equipment being specialised, not all components may exist in Ghana. Furthermore, the system design has prioritised the highest standards of energy efficiency in order to minimise the size

and expense of solar PV array required. However, there is no guarantee that best-in-class refrigerators, lights fans or air conditioning will be available in Ghana, and that the range of available products may be limited to less efficient models.

A second issue arises in relation to costs. With no large volume supply chain in place in Ghana, and a small present market, profit margins for native retailers are likely to be high. Thus whilst a western wholesaler may take a 10% margin on the sale of PV modules, in Ghana this could be as high as 100%²⁰. This argument is supported by the costs quoted for the PV modules above - £6.10/W in Ghana vs. £2.50/W in the UK. There will therefore be a cost penalty associated with sourcing niche products in Ghana.

Import Components to Ghana

In the absence of a pre-existing supply chain, the project may need to establish its own. This work has identified a range of highly efficient products which are sourced worldwide (*e.g.* genset from Australia, fridges from Germany *etc.*), but will need to be imported to Ghana.

These products can be ordered remotely and shipped directly to Ghana, where they can be collated before transporting to the site. However, this approach may be logistically complex with regards getting the equipment through customs. Whilst a solar system would be able to avoid import duty, it would not necessarily be possible to do this for all components on an individual basis²¹. There could therefore be a cost penalty for shipping directly to Ghana

Import components to England and Ship system to Ghana

A third solution would be to collate all equipment in the UK, and to export a single container to Ghana. This is more likely to get all system components through customs without paying import duty. However, this option also has a cost penalty in that there are two shipping costs (one to England and then one to Ghana), although this is the logistically simplest option.

CONCLUSIONS

This paper has developed system designs for the clinics at Ntoboroso and Hia. Each design includes the incorporation of lighting, ceiling fans, refrigeration for vaccines, air-conditioning and an allowance for other electrical uses (*e.g.* laptop, phone charging), and all appliances have been sourced to be as efficient as possible so as to minimise generation requirements. The electricity is supplied mainly from the use of *ca.* 2kW solar photovoltaic systems, coupled with battery storage. Because of the seasonal nature of the solar resource in Kumasi, a small petrol driven generator is used to provide back-up power in the rainy season, but is only expected to operate for 100 hours per year.

The total cost of the capital equipment, both generation and end-se, is estimated to be £27k and £18.25k for Ntoboroso and Hia, respectively, excluding VAT and shipping, and installation costs. Compared to the conventional means of supplying off-grid electricity from a load-following diesel genset, the projects result in CO₂ emissions savings of 36 and 23 tonnes per year.

It is believed that the designs presented offer a cost effective way of delivering electricity to the clinics, allowing greater functionality, which should be sufficient to attract qualified doctors to provide higher levels of care within the two communities.

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